THE ROYAL AERONAUTICAL SOCIETY WAS FOUNDED IN 1866

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The Journal of The Royal Aeronautical Society

with which is incorporated The Institution of Aeronautical Engineers

Edited for the Council by Capt. J. LAURENCE PRITCHARD, Hon. Fellow

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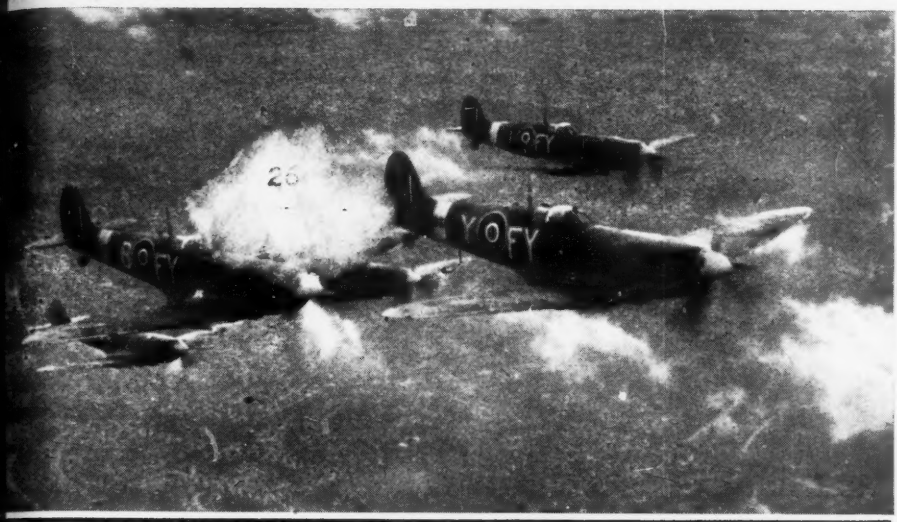

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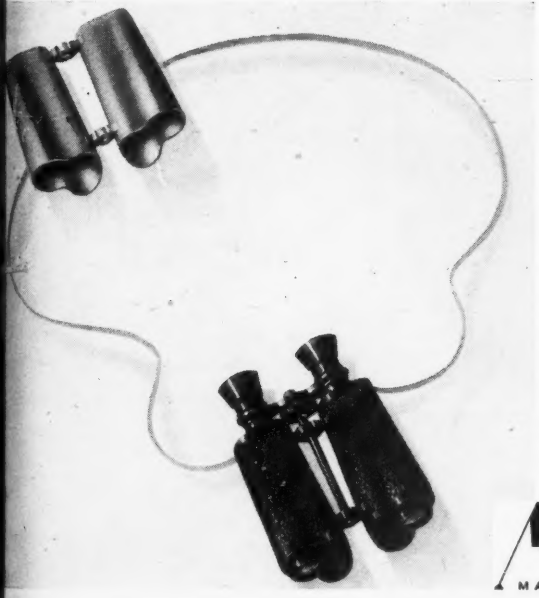

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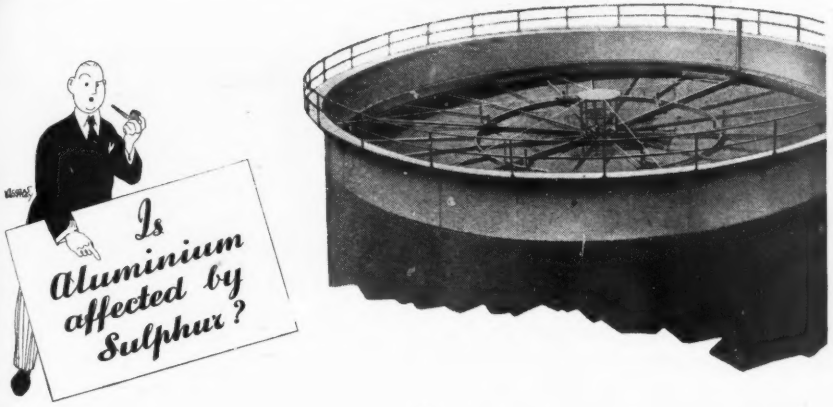

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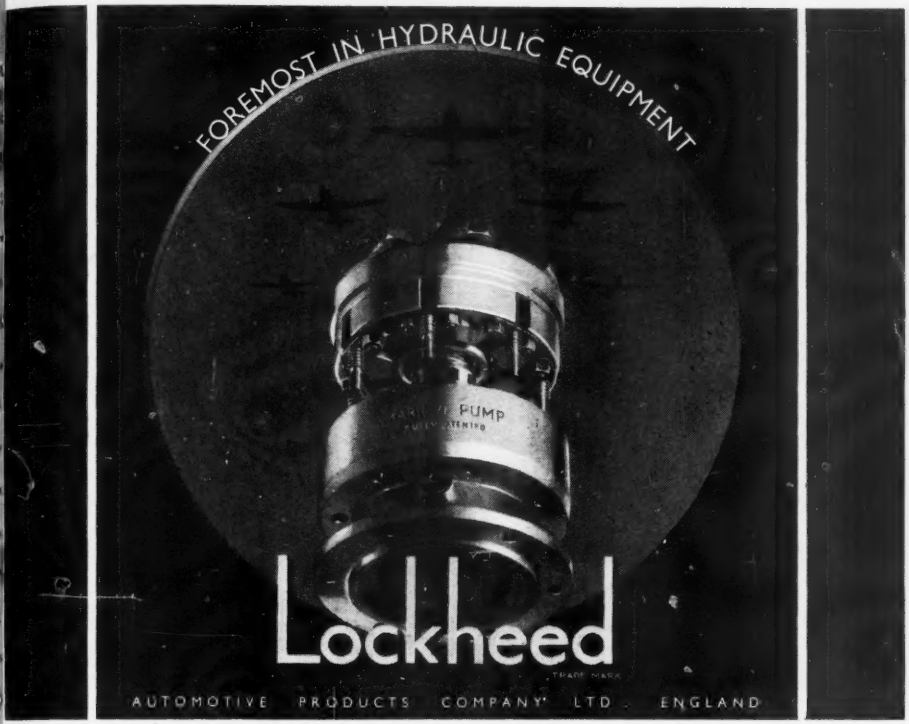
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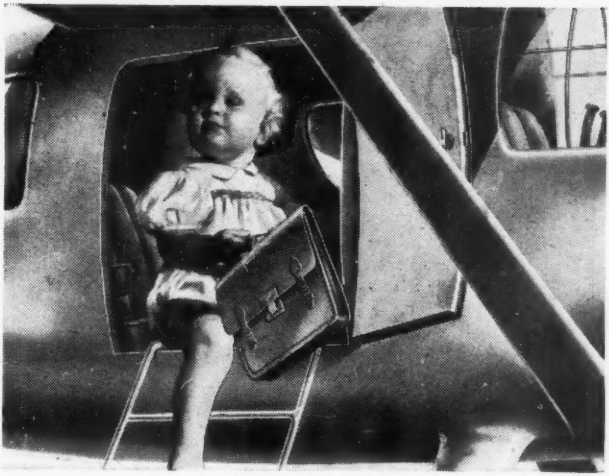

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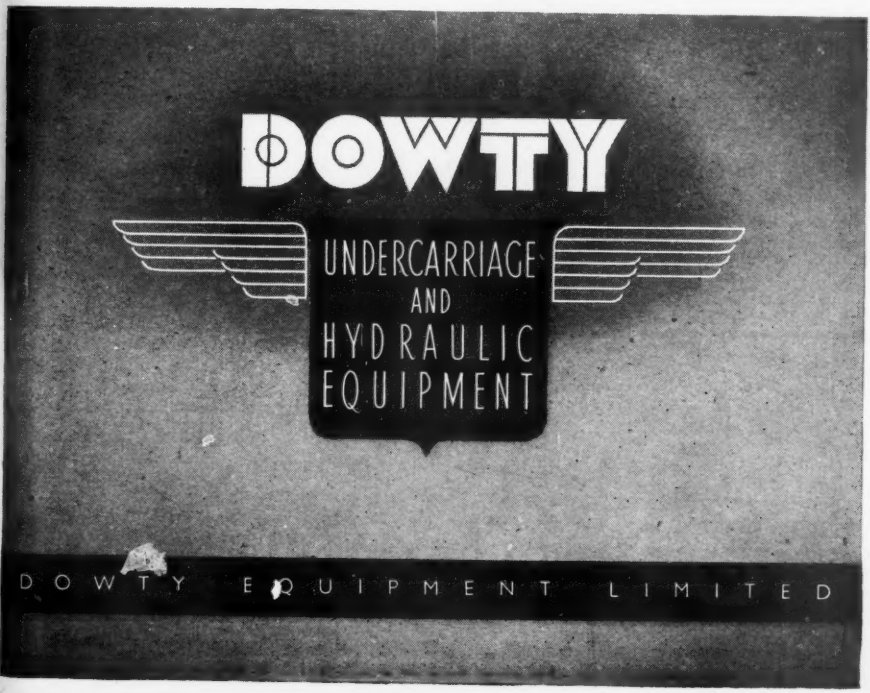

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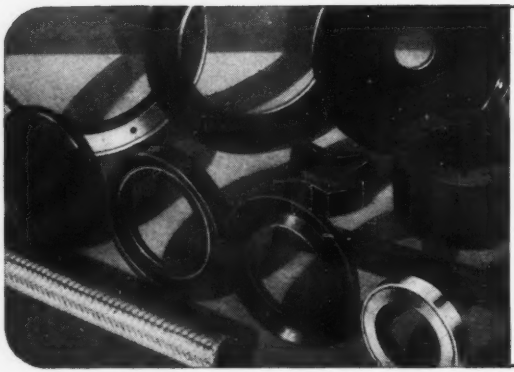

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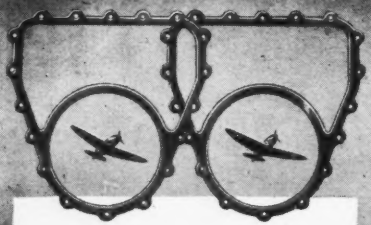

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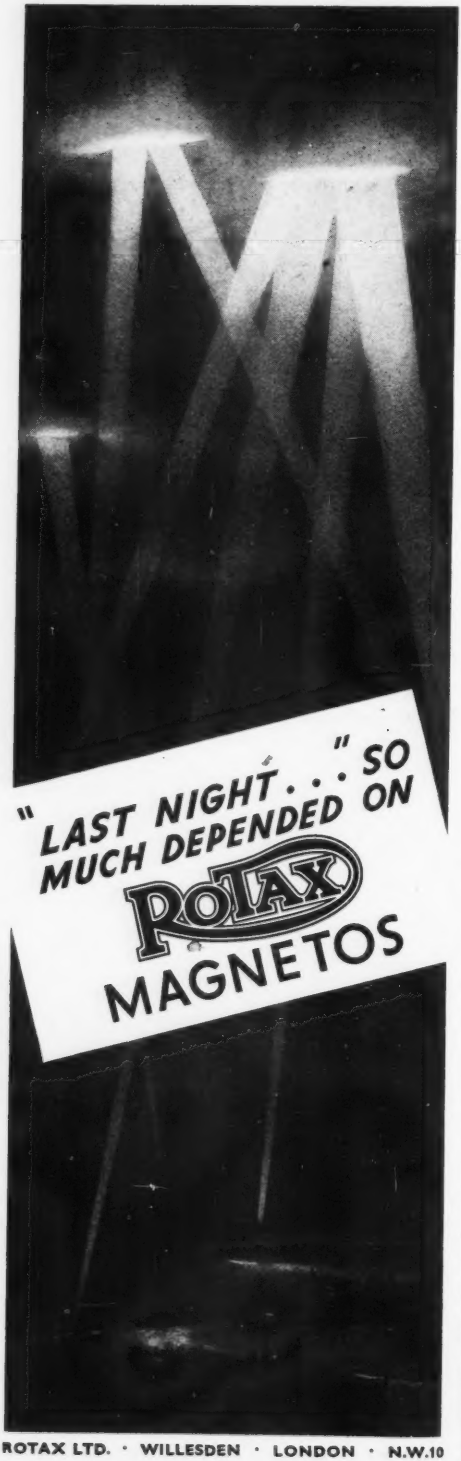

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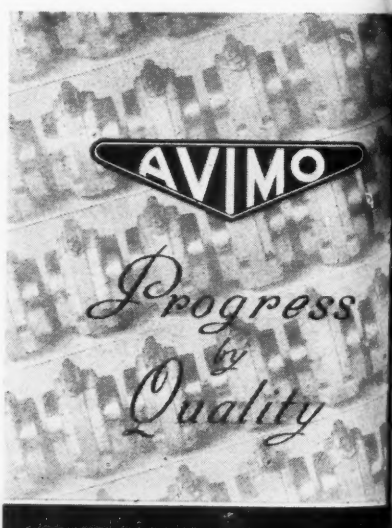

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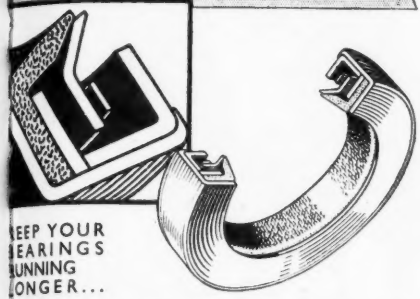

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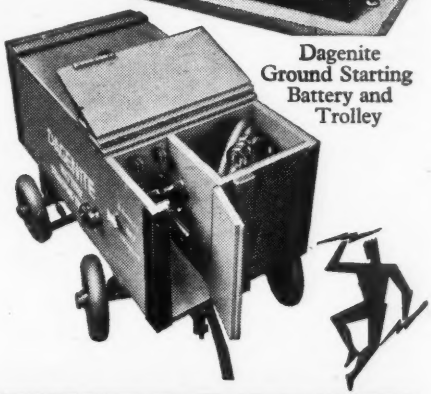

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THE JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY *was founded in* 1897 *in succession to the* ANNUAL REPORTS.

For the opinions expressed in Papers that are signed or initialled the authors alone are responsible. None of the papers or paragraphs must be taken as expressing the opinion of the Council of the Royal Aeronautical Society unless such is definitely stated to be the case.

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PRINCIPAL JANUARY CONTENTS :

German Cowlings and Quick-Release Fasteners.
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Solution of Biquadratic Equations. W. S. Brown.
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A Philosophy of Strength Factors. A. C. Pugsley.
Organization of the Manufacture of Parts. D. Tiranti.

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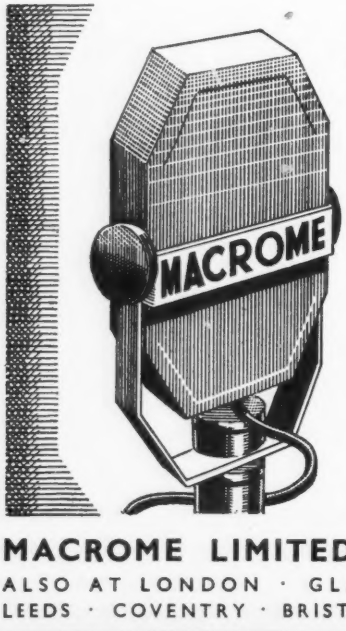

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with which is incorporated the Institution of Aeronautical Engineers

VOLUME XLVIII

MONTHLY NOTICES

JANUARY, 1944.

New Year Message.

The President, Mr. Arthur Gouge, and Council, send all members of the Society, here and overseas, their good wishes for 1944 and for the safety of themselves, and all those dear to them in this year of victory.

Special General Meeting.

NOTICE IS HEREBY GIVEN that a Special General Meeting under Rules 100 and 101 of the Royal Aeronautical Society with which is incorporated the Institution of Aeronautical Engineers, will be held on Saturday, February 5th, 1944, at 3.0 p.m., in the offices of the Society, No. 4, Hamilton Place, London, W.1, to consider alterations and additions to the Rules.

By Order of the Council,

J. LAURENCE PRITCHARD,

Secretary.

Lectures.

The following lectures have been arranged. They will be delivered at 5.30 p.m. in the Lecture Hall of the Institution of Mechanical Engineers, by kind permission of the Council of the Institution :—

February 10th, 1944.—" Flight Testing Methods," by Mr. E. T. Jones, M.Eng., A.F.R.Ae.S.

February 24th, 1944.—" Structural Features of German Aircraft," by Mr. D. M. A. Leggett, Ph.D., A.F.R.Ae.S., and Mr. H. Davison.

March 9th, 1944.—" Aerodynamic Features of German Aircraft," by Mr. M. B. Morgan, M.A., A.F.R.Ae.S., and Mr. R. Smelt, B.A.

Members of the Society are also invited to attend an Informal Meeting held under the auspices of the Institution of Mechanical Engineers, at Storey's Gate, St. James's Park, S.W.1, on Friday, 21st January, 1944, on " Future Possibilities of Diesel Engine Manufacture," at 5.30 p.m. Light refreshments will be served at 5 p.m.

Graduates' and Students' Lectures.

The following lectures have been arranged by the Graduates' and Students' Section. They will be delivered in the Library at 4, Hamilton Place, London, W.1, at 7.30 p.m. :—

Thursday, January 6th, 1944.—Commodore G. d'Erlanger on " Technical Problems in the Conversion of Military Aircraft to Civil Use."

Wednesday, January 12th, 1944.—Captain J. Laurence Pritchard, Hon. F.R.Ae.S., "The History of the Royal Aeronautical Society."

Wednesday, April 19th, 1944.—Mr. A. J. Penn on "The Design and Operation of Superchargers."

Thursday, May 11th, 1944.—Mr. J. A. Churchill on "Power Plant Installation and Design."

Council Election.

Attention is drawn to the following Rules for election of Council. Nominations for Council should be received by March 3rd, 1944. Nomination forms may be obtained from the Secretary. Attention is drawn to possible delays in the post at the present time.

RULE 17.—One half of the Council (excluding the President and the immediate Past-President if a Member of Council) shall retire annually. The members who shall retire shall be those longest in office, except as provided in Rule 77. Retiring members of Council who have served for two terms in succession (four years) shall not be eligible for re-election until the next annual election, when they will be eligible.

RULE 72.—The composition of the Council shall be as follows:—

(*a*) Not less than sixteen shall be elected from the technical or scientific grades of the R.Ae.S., that is to say, from among the Fellows, Associate Fellows, Associates and Graduates.

(*b*) Of these sixteen, four at least shall be Fellows.

RULE 73.—Nominations of candidates for election to the Council must be received by the Secretary not less than twenty-one days before the Annual General Meeting, with an intimation in writing by the Candidates that they are willing to serve. Nominations must be signed by one supporter and two seconders, who must be each entitled to vote in the R.Ae.S.

Journal Binding.

Owing to increased costs, the prices of binding of all Journals will be as follows:—

	s.	d.
Including Library Catalogue	10	0
1943 Volume	8	6
1942 Volume	9	0
1941 Volume with Catalogue of Library ...	10	0
1941 Volume without Catalogue of Library ...	9	0
Library Catalogue (separately bound) ...	9	0
Previous Volumes	9	0

Journals for binding should be sent direct to The Lewes Press, Friars Walk, Lewes, Sussex, and the remittance to the Secretary at the office of the Society.

Acknowledgments.

The Council acknowledge with grateful thanks the gift by Captain Ellison Hawks of a complete set of the aeronautical books and pamphlets published by "Real Photographs Co., Ltd.," between 1941 and the present date.

Annual Subscriptions of Members.

Members are reminded that their 1944 subscriptions will become due on 1st January, 1944.

The Council are very grateful to all those members who have offered to forego their Journals for the duration of the war. The same reductions will be made to the 1944 subscriptions of these members as applied to the 1943 subscriptions. Subscriptions of Fellows, Associate Fellows, Graduates, Companions and Founder Members, who have given up their Journals will therefore be reduced by 10s. 6d. Associates will receive the reduction already laid down in the Rules and the low subscription at present paid by Students does not permit any reduction to be made.

The following will be the rates for 1944 therefore:—

	Home receiving Journal.	Home not receiving Journal.	Abroad receiving Journal.	Abroad not receiving Journal.
	£ s. d.	£ s. d.	£ s. d.	£ s. d.
Founder Members	2 2 0	1 11 6	2 2 0	1 11 6
Fellows	4 4 0	3 13 6	3 3 0	2 12 6
Associate Fellows	3 3 0	2 12 6	2 2 0	1 11 6
Associates	2 2 0	1 1 0	2 2 0	1 1 0
Graduates (age 21-25) ...	2 2 0	1 11 6	2 2 0	1 11 6
,, (age 26-28) ...	2 12 6	2 2 0	2 12 6	2 2 0
Students	1 1 0	1 1 0	1 1 0	1 1 0
Companions	2 2 0	1 11 6	2 2 0	1 11 6

Election of Members.

Associate Fellows.—Thomas James McOram Campbell, Bernard Cecil Frost (from Associate), Ronald Frank Davis, Peter Burns Hovell, John C. Leslie, Peter Sidney Saunders, Leonard Smith (from Graduate).

Associates.—Francis Daniel Atkinson Ashley, William Bogatto, Eric Stuart Caro, James Joseph Casey, Arthur Percival Cowling, Michael Dorrington Day, John Joseph Dydan, Hugh James Fitzpatrick, Gisbert David Spencer Garrett, George Henry Hartup, Richard Davies Millar, Wilfred Ernest Martin Miller, James Parsons, Thomas George Preston (from Student), Glyndwr Rees, Linnard Harold Scowen, Arthur Charles Wadge, Bryan Howard Moir Winslett.

Graduates.—Trevor Peter Boswell (from Student), William Edward Breacker, Sanderson Buchanan, Charles Hamilton Crosbie, Peter Anthony Curry (from Student), Harold Davies, George William Ellis, Murray Ellins (from Student), Harold William Harris (from Student), John Reginald Lupton, Albert Edward Vaughan, James Norman Verner, Alfred John Walder.

Companion.—Peter Edward Radcliffe.

Students.—Norman Andrews, Brian Baldock, Owen Richard Ballard, Ian Kenneth Bennett, George Brewster, John Woodbury Bugler, Kenneth Frank Callis, Patrick James Campbell, Nevil John Eugene Chaplin, Kenneth Sydney Robert Child, Nora Helen Darby, Thomas James Dorricott, Alfred Edgar, Albert George Mark Elliott, Stanley Hargreaves Ellis, Leslie Allan Firth, Douglas Somerville Fuller, John Kenneth Gilbert, Cyril Aubrey Glew, Karl Heinz Grote, Robert Edward Thirlby Hack, John Maxwell Hands, Robert Malcolm Hay, George Winzar Horne, Gordon Thomas Hudson, Peter Frank Jeffcoate, Hans J. Peter Bruno Kahn, Frederick Stanley Kinsey Lee, Anthony Brian Davies Leigh, Thomas William McGowan, Glanville Thomas Magor, David Michael, Kenneth Herbert Miles, Hugh Derrick Thomas Owens, Wilfred Edwin

Pearce, Lionel Ralph Phillips-Francis, Frank Pilkington, Ronald Arthur David Ranson, John Eric Rhodes, Samuel George Robbins, Donald Frederick Harvey Rushton, Ronald Alfred Smithers, John Morton Spong, Samuel David Thomas, John Richard Thirkettle, David John Truscott, Leslie Alfred Wade, Gilbert Arthur Whyte-Venables, Ronald Wilson, James Middleton Worthington.

Additions to Library.

Pamphlets in italics with location reference following in brackets.
Books marked * may not be taken out on loan.

A.a.300.—An Introduction to Principles of Flight. W. F. Ware. Macmillan and Co. 1943. 3/-.

B.a.293.—*Studenten-Bummel durch Afrika. (Description of Bücker Student Aeroplane.) Bücker Flugzeugbau.* 1939. *(Stencil.)* (Y.3.ii.B.)

B.a.294.—*Technical Description of the Vultee Transport. (Airplane Development Corpn. (U.S.A.). (Stencil.) (Undated, ca.* 1939.) (Y.3.ii.V.)

B.a.295-296.—*The Praga E. 214; the Praga E. 241. Ceskomoravska-Kolben-Danek Co.* 1937. *(Stencils.)* (Y.3.ii.P.)

B.a.298.—*The Case for the Flying Boat. Saunders-Roe, Ltd.* 1943. (PB.2.a.7.)

B.a.299.—*Junkers Ju. 90. Junkers A/G.* 1937. *(Stencil.)* (Y.3.ii.J.)

B.a.300.—*Blind Flying Taught Indoors. (Pictures of Link Trainer.) Illustrated London News, Nov. 20,* 1937. (Y.3.ii.L.)

B.a.301.—Fighters. Capt. Ellison Hawks. Real Photographs Co. 1943. 5/-.

B.a.302.—*American Type Designations. Real Photographs Co.* 1943. 1/-. (PB.2.a.8.)

B.a.303.—*Aircraft Classification. Real Photographs Co.* 1942. 1/6. (PB.2.a.9.)

B.a.304-305.—*Aircraft Comparisons: I, Single-Engined Aircraft; II, Multi-Engined Aircraft. Real Photographs Co.* 1942. *9d. and 1/3 respectively.* (PB.2.a.10 and 11.)

B.a.306-307.—*Aircraft Armament, Past and Present. I, Machine Guns, etc.; II, Gun Turrets, etc. Real Photographs Co.* 1942. *1/3 each.* (PB.2.a.12 and 13.)

B.d.5.—*Aircraft Carriers of Great Britain, U.S.A. and the Axis Nations. Real Photographs Co.* 1942. 1/6. (PB.2.c.2.)

B.d.6 and 7.—*Ship Flying and Aircraft Carriers. Comdr. Peter Bethell. Reprint from "Engineering," July 2, 16, 23, August 6, 20, 27,* 1943. *(Two copies.)* (Y.9/S.)

*B.g.128.—*Warplanes Series, Nos. 1-7. Real Photographs Co.* 1941-1943. *Price 1/6 each (except Nos. 3 and 5, 1/3 each).* Bound in one volume.

B.g.129.—*Silhouettes d'Avions Classées par Analogie. L'Aéronautique Militaire.* 1917. (PB.5/1.)

*B.g.130.—The Observer's Book of Airplanes. Joseph Lawrence. Frederick Warne and Co. 1943. 4/-.

*BB.b.107.—Airplane Structural Analysis and Design. E. E. Sechler and L. G. Dunn. John Wiley, New York. 1942. $4.

D.b.196.—Development of International Air Transport Services. Civil Aeronautics Board, U.S.A. (Press release, Oct. 15th, 1943.) (Y.6.b.27.)

D.b.197.—*Is this the End of Civil Aviation in Britain? C. G. Grey. (Article in "The Sphere," April 13th,* 1940.) (Y.6.b.26.)

EE.b.77.—*The De Havilland Gipsy XII Engine. De Havilland Aircraft Co.* 1938. *(Stencil.)* (Y.7.D.)

G.a.63 and 64.—Engineering Materials. Vol. I: The Ferrous Metals; Vol. II: Non-Ferrous and Organic Materials. (2nd Ed.) A. W. Judge. Sir Isaac Pitman. 1943. 25/- and 30/- respectively.

L.a.47.—*Air Crew Exercises for the A.T.C. Air League of the British Empire.* 1943. 1/-. (PL.1.a.7.)

L.d.97.—The Air Mariner. D. C. T. Bennett. (2nd Ed.) Sir Isaac Pitman. 1943. 7/6.

L.d.98.—*Navigation: Finding the Way at Sea. Real Photographs Co.* 1943. 1/6. (PL.1.b.8.)

L.d.99.—*Air Navigation. Real Photographs Co.* 1943. 1/6. (PL.1.b.9.)

L.e.11.—Map Reading and Avigation. Richard M. Field and Harlan T. Stetson. Chapman and Hall. 1943. 15/-.

L.j.89.—*Method of Filming Capt. Dieterle's Speed Record. Askania-Werke, A/G. (Press release, in German.)* 1939. (Y.16/21.)

L.j.90.—*Layout Reproduction as Applied in the Aircraft Industry. A. Hessell Tiltman. Lecture before the Association for Scientific Photography, Oct. 23rd,* 1943. *(Stencil.)* (Y. 16/22.)

R.f.92.—Men and Wings. Assen Jordanoff. Curtiss-Wright Airplane Division. 1942. 50 c.

S.a.134.—*Synopsis of British Air Effort During the War. Air Ministry. H.M.S.O.* 1919. (Y.17.b.9.)

S.a.135.—Above and Beyond Palestine. C. E. Hughes. Ernest Benn. 1930.

S.b.128.—*With the R.A.F. in France. Article in "The Sphere," Jan. 27,* 1940. (Y.17.c.R.)

S.b.129.—*The Fleet Air Arm. Frank C. Bowen. Article in "The Sphere," April 6,* 1940. (Y.17.c.F.)

S.b.130.—*A Short History of the R.A.F. Capt. Ellison Hawks. Real Photographs Co.* 1943. 3/-. (PS.2/12.)

S.b.131.—Technical Notes: Royal Flying Corps. H.M.S.O. 1916.

S.e.74.—*Naval Episodes. Real Photographs Co.* 1943. 1/6. (PS.3.a.18.)

S.e.75.—Over to You. (2nd Series of R.A.F. Broadcasts.) Ministry of Information. H.M.S.O. 1943. 9d.

S.e.76.—Front Line, 1940-1941. Ministry of Information. H.M.S.O. 1942. 2/-.

T.a.107.—*Captain Frederick Burnaby. (Details of Career.) Privately printed. Undated.* (Y.5.B.)

*V.5/49.—Proceedings of the Institution of Mechanical Engineers. Vol. 149, Jan.-June, 1942.

*X.e.51.—Institution of Naval Architects: Members' List, September, 1943.

J. LAURENCE PRITCHARD, *Secretary and Editor.*

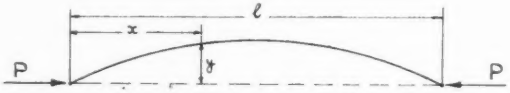
APPROXIMATE SOLUTION FOR TAPERED PIN-ENDED STRUTS.

By HAYDN TEMPLETON, B.Sc., A.F.R.Ae.S.

(of the Design Staff of Sir W. G. Armstrong Whitworth Aircraft, Ltd.).

Approximate solutions for the critical load of an axially loaded strut, and for the deflection produced in an eccentrically loaded strut, are obtained by the Energy Method. For most practical purposes these solutions compare favourably with solutions based on successive approximation, since for the same accuracy the time required for a solution by successive approximation is much greater.

Axially loaded strut.



Assume that, in the critical condition, the strut experiences a lateral deflection given by

$$y = a \sin\left(\frac{\pi x}{l}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The bending moment corresponding to this deflection is then

$$M = Py = Pa \sin\left(\frac{\pi x}{l}\right)$$

and the strain energy of bending of the strut is

$$V = \int_0^l \left(\frac{M^2}{2EI}\right) dx = \left(\frac{P^2 a^2}{2E}\right) \int_0^l \sin^2\left(\frac{\pi x}{l}\right) \cdot \left(\frac{dx}{I}\right) \quad . \quad . \quad . \quad (2)$$

The condition for neutral equilibrium (*i.e.*, critical load) is obtained when the work done by the external forces during a lateral deflection of the strut (without any change of load) equals the increment of strain energy of the strut due to the same lateral deflection.

Now the distance by which the ends of the strut approach each other due to the lateral deflection is

$$\lambda = \int_0^l (ds - dx) = \int_0^l \left(\sqrt{\left\{ 1 + \left(\frac{dy}{dx}\right)^2 \right\}} - 1 \right) dx$$

Neglecting the fourth and higher powers of dy/dx gives

$$\lambda = \tfrac{1}{2} \int_0^l \left(\frac{dy}{dx}\right)^2 . \, dx = \left(\frac{\pi^2 a^2}{2l^2}\right) \int_0^l \cos^2\left(\frac{\pi x}{l}\right) . \, dx = \frac{\pi^2 a^2}{4l}$$

The work done by the external loads P, P during the lateral deflection is then

$$T = P\lambda = \frac{P\pi^2 a^2}{4l} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Equating V and T from equations (2) and (3) then gives

$$\frac{P\pi^2a^2}{4l}=\left(\frac{P^2a^2}{2E}\right)\int_0^l \sin^2\left(\frac{\pi x}{l}\right).\left(\frac{dx}{I}\right)$$

$$\text{or } P=\left(\frac{\pi^2}{K}\right)\left(\frac{EI_{1/2}}{l^2}\right) \quad . \quad . \quad . \quad . \quad . \quad (4)$$

$$\text{where } K=2\int_0^l\left(\frac{I_{1/2}}{I}\right)\sin^2\left(\frac{\pi x}{l}\right).d\left(\frac{x}{l}\right) \quad . \quad . \quad . \quad . \quad (4a)$$

and $I_{1/2}$ is the value of the moment of inertia I at the centre of the strut.

Equation (4) gives the value of the critical load P, and the factor K can be calculated by graphical integration for any given values of I.

APPROXIMATION TO I.

If we assume that, for each half strut length from $x=0$ to $x=l/2$,

$$\frac{I}{I_{1/2}}=A+\frac{B}{2}\left\{\frac{x}{l}-\left(\frac{1}{2\pi}\right)\sin\left(\frac{2\pi x}{l}\right)\right\} \quad . \quad . \quad . \quad (5)$$

then expression (4a) for K becomes directly integrable, thus

$$K=4\int_0^{\frac{1}{2}}\{\sin^2(\pi x/l).d(x/l)\}/\{A+\tfrac{1}{2}B\{(x/l)-(1/2\pi)\sin(2\pi x/l)\}\}$$
$$=(4/B)\log_e(1+B/4A) \quad . \quad . \quad . \quad . \quad (6)$$

Expression (5) represents a curve, concave in form, with ordinates increasing with increasing x/l, and may therefore present a reasonable approximation to the actual curve of I. Since (5) contains two arbitrary constants, A and B, it can be made to fit the actual values of I at two points, and choosing for these the quarter-length and half-length, we have

at $\frac{x}{l}=\frac{1}{4}$ $\qquad \frac{I_{1/4}}{I_{1/2}}=A+\frac{1}{2}B\left(\frac{1}{4}-\frac{1}{2\pi}\right)=m$ say,

at $\frac{x}{l}=\frac{1}{2}$ $\qquad 1=A+\frac{1}{2}B$ ($I_{1/4}$ being the value of I at $x/l=1/4$)

from which $A=\left\{\frac{2\pi}{(2+\pi)}\right\}m-\frac{(\pi-2)}{(2+\pi)}=1.222\,m-0.222$

and $B=\left\{\frac{8\pi}{(2+\pi)}\right\}(1-m)=4.89\,(1-m)$.

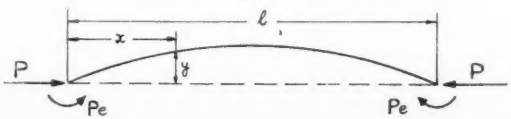
Substituting these values in (5) and (6) gives

$$\frac{I}{I_{1/2}}=(1.222\,m-0.222)+2.445\,(1-m)\left\{\frac{x}{l}-\left(\frac{1}{2\pi}\right)\sin\left(\frac{2\pi x}{l}\right)\right\} \quad . \quad (7)$$

$$\text{and } K=\left\{\frac{0.818}{(1-m)}\right\}\log_e\left\{\frac{1}{(1.222\,m-0.222)}\right\} \quad . \quad . \quad . \quad (8)$$

If equation (7) gives values of I that are mostly *less* than the actual values of I, then the value of the critical load obtained from (4) and (8) will be too low. Similarly, an overestimated I gives too high a value for the critical load.

Eccentrically loaded strut.



Forces at the ends of the strut are equivalent to an axial load P combined with a moment Pe, e being the end eccentricity. Assume that the lateral deflection y corresponding to the load P is

$$y = cx\,(l-x) + a\sin\left(\frac{\pi x}{l}\right) \quad . \quad . \quad . \quad . \quad (9)$$

$$\text{from which } \frac{dy}{dx} = c\,(l-2x) + \left(\frac{a\pi}{l}\right)\cos\left(\frac{\pi x}{l}\right) \quad . \quad . \quad . \quad (10)$$

$$\text{and } \frac{d^2y}{dx^2} = -2c - \left(\frac{a\pi^2}{l^2}\right)\sin\left(\frac{\pi x}{l}\right). \quad . \quad . \quad . \quad (11)$$

Equations (9) to (11) satisfy the conditions of zero deflection and positive moment at the two ends, where

$$M = Pe = -EI_0\frac{d^2y}{dx^2} = EI_0\,(2c)$$

$$\text{from which } c = \frac{Pe}{2EI_0} \quad . \quad . \quad . \quad . \quad . \quad (12)$$

The second constant a in (9) can be determined by the Energy Method. The strain energy of bending of the strut is

$$V = \int_0^l \left(\frac{M^2}{2EI}\right)dx = \int_0^l \left(\frac{EI}{2}\right)\cdot\left(\frac{d^2y}{dx^2}\right)^2 dx \quad . \quad . \quad . \quad (13)$$

Now if the constant a is increased by a small amount δa, then the strain energy V will be increased by an amount δV. At the same time, due to the extra deflection of the strut, the external loads P and moments Pe do amounts of work δT_1 and δT_2 respectively. Equating increase in strain energy to work done gives

$$\delta V = \delta T_1 + \delta T_2$$

or

$$\frac{\partial V}{\partial a} = \frac{\partial T_1}{\partial a} + \frac{\partial T_2}{\partial a} \quad . \quad . \quad . \quad . \quad . \quad (14)$$

From (13)

$$\frac{\partial V}{\partial a} = \int_0^l EI\left(\frac{d^2y}{dx^2}\right)\cdot\left(\frac{\partial}{\partial a}\right)\left(\frac{d^2y}{dx^2}\right) . dx$$

$$= \int_0^l EI\left\{2c + \left(\frac{a\pi^2}{l^2}\right)\sin\left(\frac{\pi x}{l}\right)\right\}\left(\frac{\pi^2}{l^2}\right)\sin\left(\frac{\pi x}{l}\right) . dx \quad . \quad . \quad (15)$$

The distance by which the ends of the strut approach each other from the straight to the deflected condition is, as before,

$$\lambda = \tfrac{1}{2}\int_0^l \left(\frac{dy}{dx}\right)^2 . dx$$

and since $\delta T_1 = P\,.\,\delta\lambda$ then

$$\frac{\partial T_1}{\partial a} = P\frac{\partial \lambda}{\partial a} = P\int_0^l \left(\frac{dy}{dx}\right)\cdot\left(\frac{\partial}{\partial a}\right)\left(\frac{dy}{dx}\right) . dx$$

$$= P\int_0^l \left\{c\,(l-2x) + \left(\frac{a\pi}{l}\right)\cos\left(\frac{\pi x}{l}\right)\right\}\left(\frac{\pi}{l}\right)\cos\left(\frac{\pi x}{l}\right) . dx$$

or

$$\frac{\partial T_1}{\partial a} = P\left(\frac{4cl}{\pi} + \frac{\pi^2 a}{2l}\right) \quad . \quad . \quad . \quad . \quad . \quad (16)$$

For the work done by the moments Pe, it is necessary to consider the change in slope at the ends of the strut.

$$\text{At } x=0, \text{ slope } \theta=\left(\frac{dy}{dx}\right)_{x=0}=cl+\frac{a\pi}{l}$$

Since the total work done by the two end moments equals twice the work done by one, then

$$\delta T_2=2Pe\,.\,\delta\theta$$

and

$$\frac{\delta T_2}{\delta a}=2Pe\frac{\delta\theta}{\delta a}=2Pe\frac{\pi}{l} \quad . \quad . \quad . \quad . \quad . \quad (17)$$

Substituting in equation (14) from (15), (16) and (17) now gives

$$\int_0^l EI\left\{2c+\left(\frac{a\pi^2}{l^2}\right)\sin\left(\frac{\pi x}{l}\right)\right\}\frac{\pi^2}{l^2}\sin\left(\frac{\pi x}{l}\right).dx=P\left(\frac{4cl}{\pi}+\frac{\pi^2 a}{2l}\right)+2Pe\left(\frac{\pi}{l}\right)$$

from which

$$a=\frac{\left\{P\left(\frac{4cl}{\pi}+\frac{2\pi e}{l}\right)-\int_0^l\left(\frac{2\pi^2}{l^2}\right)EIc\sin\left(\frac{\pi x}{l}\right).dx\right\}}{\left\{\int_0^l\left(\frac{\pi^4}{l^4}\right)EI\sin^2\left(\frac{\pi x}{l}\right).dx-\frac{\pi^2 P}{2l}\right\}}$$

Writing $\beta=Pl^2/EI_0$, then $c=Pe/2EI_0=\beta e/2l^2$, and we get

$$\frac{a}{e}=\beta\,.\,\frac{\left\{\left(\frac{2}{\pi}\right)\left(\frac{\beta}{\pi^2}+1\right)-\int_0^l\left(\frac{I}{I_0}\right)\sin\left(\frac{\pi x}{l}\right)d\left(\frac{x}{l}\right)\right\}}{\left\{\pi^2\int_0^l\left(\frac{I}{I_0}\right)\sin^2\left(\frac{\pi x}{l}\right)d\left(\frac{x}{l}\right)-\frac{\beta}{2}\right\}} \quad . \quad . \quad (18)$$

(I_0 being the value of I at the end.)

The integrals in (18) can be calculated graphically for any given values of I, and the constant "a" determined. Substituting for "a" and "c" in equation (9) gives the complete deflection y, and hence the bending moment and total stress at any point.

In particular, at the centre of the strut where the deflection is a maximum, we have from (9)

$$\frac{y\,(\max)}{e}=\frac{cl^2}{4e}+\frac{a}{e}=\frac{\beta}{8}+\frac{a}{e} \quad . \quad . \quad . \quad . \quad (19)$$

APPROXIMATION TO I.

If we assume that, for each half strut length from $x=0$ to $x=l/2$,

$$\frac{I}{I_0}=A+B\left(\frac{x}{l}\right)+C\left(\frac{x}{l}\right)^2 \quad . \quad . \quad . \quad . \quad (20)$$

then the integrals in (18) become directly determinable, and we have

$$\frac{a}{e}=\beta\,.\,\frac{\left\{\left(\frac{2}{\pi}\right)\left(\frac{\beta}{\pi^2}+1\right)-\left(\frac{2A}{\pi}+\frac{2B}{\pi^2}\right)+0.0736\,C\right)\right\}}{\left\{\pi^2\left(\frac{A}{2}+0.1756\,B+0.067\,C\right)-\frac{\beta}{2}\right\}} \quad . \quad (21)$$

Since expression (20) contains three arbitrary constants, it can be made to fit the actual values of I at three points. Choosing for these the end, quarter-length, and half-length, we have

$$\text{at } x=0 \qquad 1=A$$

$$\text{at } x=\frac{l}{4} \qquad \frac{I_{1/4}}{I_0}=A+\frac{B}{4}+\frac{C}{16}$$

$$\text{at } x=\frac{l}{2} \qquad \frac{I_{1/2}}{I_0}=A+\frac{B}{2}+\frac{C}{4}$$

$$\left.\begin{aligned} \text{from which } A&=1 \\ B&=(2/I_0)\,(4I_{1/4}-I_{1/2}-3I_0) \\ \text{and } C&=(8/I_0)\,(I_{1/2}-2I_{1/4}+I_0) \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (22)$$

Here again, if equation (20) underestimates the actual values of I then (21) will overestimate the deflection, and vice versa.

NUMERICAL EXAMPLE.*

A strut, symmetrical about the centre, has a moment of inertia for each half-length given by

$$I=0.4\,(1+1.162\,x/l)^2\,I_{1/2}. \quad . \quad . \quad . \quad . \quad (23)$$

1. AXIAL LOAD.

Putting $x/l=1/4$ in (23) gives $I_{1/4}=0.665\,I_{1/2}$

$$m=\frac{I_{1/4}}{I_{1/2}}=0.665$$

Using the approximate form for K given by equation (8) gives

$$K=(0.818/0.335)\log_e 1.692=1.285$$

and the corresponding critical load from (4) is

$$P=7.68\frac{EI_{1/2}}{l^2}$$

Alternatively, calculating K as in (4*a*) by graphical integration gives $K=1.292$, for which

$$P=7.64\frac{EI_{1/2}}{l^2}$$

The exact value for the critical load, as quoted by Ratzersdorfer, is $7.61\,EI_{1/2}/l^2$.

2. ECCENTRIC LOAD.

Length $l=30$ ins.
Moment of inertia at centre $I_{1/2}=0.15$ ins.^{4}.
Eccentricity $e=0.05$ ins.
Young's Modulus $E=10\times10^6$ lbs. per ins.^{2}.
Load $P=8{,}000$ lbs.

Then

$$I_0=0.4\,I_{1/2}=0.06 \text{ ins.}^4.$$

and

$$\beta=\frac{Pl^2}{EI_0}=\frac{(8{,}000\times900)}{(10\times10^6\times0.06)}=12.0.$$

Since the variation of I is parabolic, equation (21) is the exact form of (18).

Now

$$I/I_0=(1+1.162\,x/l)^2=1+2.324\,(x/l)+1.350\,(x/l)^2$$

and hence

$$A=1,\ B=2.324,\ C=1.350.$$

Substituting these values, together with that of β, in (21) gives $a=0.0318$.

* Taken from "Determination of the Buckling Load of Struts with Successive Approximations" by Dr. J. Ratzersdorfer. R.Ae.S. Journal, March, 1943.

Also,

$$c=\frac{\beta e}{2l^2}=\frac{(12.0\times 0.05)}{(2\times 900)}=\frac{1}{3{,}000}$$

Substituting these values of a and c in (9) gives

$$y=\frac{x\,(l-x)}{3{,}000}+0.0318\,\sin\left(\frac{\pi x}{l}\right)$$

and at the centre of the strut ($x=l/2$), y (max)$=0.1068$ ins.

The solution can be checked by a double integration of the bending moment corresponding to the deflection y, which should give the same deflection, thus

$$\text{deflection } y=\int\int\left(\frac{P}{E}\right)\left\{\frac{(y+e)}{I}\right\}\,.\,dx\;dx$$

Performing this double integration graphically gives a final deflection y at the centre of the strut of 0.1075 ins., which is different from the original calculated value of 0.1068 ins. by less than 1 per cent. The difference between the final and original values of y is greater than this at points nearer the end of the strut, but expressed as a percentage of the total deflection $(y+e)$ from the load-line this difference is nowhere greater than 2.4 per cent. The error of the approximate solution is therefore seen to be reasonably small.

COMPARISON OF VARIOUS METHODS FOR DETERMINING FLIGHT SPEED AT GREAT ALTITUDES.*

R. SCHMIDT.

Luftwissen, Vol. 9, No. 9, Sept., 1942, pp. 270-275.
Translated by L. J. GOODLET.

The speed of flight of an aircraft at high altitudes is still usually determined by the indirect method of measuring the dynamic pressure in flight. The acknowledged defects of this method—the effect of interference by near parts of the aircraft on the static pressure at the tapping point, the necessity of calibration of the pressure readings by tedious quadrilateral flights over measured ground distances or a suspended static head, the indeterminate effect of the Mach number at high speeds, inaccuracy of the air temperature measurements owing to stagnation of the flow at the instrument, errors of the elastic pressure capsule owing to hysteresis and temperature variations, and the inaccuracy of the mean values obtained by averaging the measured dynamic pressures—have all contributed to raise a demand for a simpler and more accurate method of airspeed measurement.

This urgent need has produced the development of the " Dornier Air Log " (see Jahrbuch der deutschen Luftfahrtforschung, 1938, Vol. 1, p. 583). The advantages of this instrument over the standard method of dynamic-pressure measurement, all result from the application of the physical principle that the revolutions of a propeller running in frictionless bearings are always exactly proportional to the velocity of the incident flow and governed only by its value. If such freedom from bearing friction can be assured, and the propeller of the log placed beyond the influence of the disturbed flow surrounding the aircraft, the speed of flight can be simply measured by the number of revolutions of the propeller of the log in unit time. Both objects are completely attained in the " Dornier Air Log "; frictional effects are eliminated by a special design of the rotor shaft bearings, and a frictionless photo-electric method of transmitting the recorded rotor revolutions to the indicating mechanism; while the arrangement for removing the log rotor out of the region of disturbance of the aircraft has been considerably improved, compared with air logs of usual type, by the provision of depressor vanes of special design. Owing to the insignificant frictional losses, the air log is almost completely unaffected by differences in altitude; furthermore, since the rotor is removed from the influence of disturbance by near parts of the aircraft, it is unnecessary to calibrate the instrument for each series of readings, provided the pitch of the rotor has been determined initially with sufficient accuracy, by calibration flights over a measured distance, or wind tunnel tests.

It was desired to test the efficacy of these measures by comparative tests with other methods of determining airspeed. The difficulty in the arrangement of such comparative tests is entirely due to the fact that direct correlation of air log readings with dynamic pressure readings is impossible, since the latter results are under all circumstances qualitatively inferior, while the required basis of comparison must be of a higher degree of accuracy than the standard methods of measuring dynamic pressure in flight. A suitable basis of comparison has therefore been found in a method of calibration flights over a sufficiently long measured ground distance, in which the instant of passage through the terminal points of the course was determined by gyro-stabilized vertical-sight telescopes.

* Published by permission of the Ministry of Aircraft Production, R.T.P.

The method simultaneously furnishes valuable information on the amount of error involved in direct calibration by quadrilateral flights, and should therefore be of interest for all aeronautical engineers.

METHODS OF AIRSPEED MEASUREMENT: QUADRILATERAL CALIBRATION FLIGHTS.

The method of determining airspeed by calibration flights over a measured quadrilateral ground course is of comparatively high accuracy. In the actual case, the degree of accuracy was further improved by the use of a particularly long measuring course, viz., a quadrilateral of about 4×20 km. sides. With a mean airspeed of 130 m./sec. the time taken over each leg of the course is about 155 secs. The error due to inaccuracies in the stop-watch timing did not exceed about ± 0.2 sec., or 0.0013 of the measured values. The difficulty of determining the exact instant of transit through the terminal and turning points of the measuring course was overcome by the use of vertical-sight telescopes in which the cross-wires are steadied by a gyroscopic attachment on a pendulum-controlled cardan suspension maintaining them in the true vertical.

The measurements obtained in the quadrilateral calibration flights were evaluated as usual by plotting the measured speed over the ground " Vg " along the true courses, and graphical construction of the circle passing through all four measuring points. The centre of the circle then usually shows a small quadrilateral termed the " Quadrangle of error," corresponding to the accuracy of the measurements and defining the greatest possible amount of error in the resultant mean speed of flight. This amount of error is governed by three factors:—

1. Stop-watch timing error.
2. Wind fluctuations during the period of measurement.
3. Variations in the speed of flight over the four legs (sides) of the measuring course.

As already demonstrated, stop-watch timing errors are negligibly small. Wind variations will also be small, particularly at high altitudes, and if weather conditions during the test are stable. Errors owing to variable speed of flight over the four legs of the course can easily be corrected by using the air log, as follows: The mean number of revolutions of the log rotor can be very accurately read off on the dial of the instrument; these, however, must be exactly proportional to the mean speed of flight over each leg of the course. Since the latter will not be uniform over all four legs, the mean number of revolutions must vary correspondingly; by reducing these mean values to a common mean over the whole course, the measured " Vg " values of speed over the ground can be corrected in the same proportion, the resulting " Vg " values over the ground will then correspond to the constant mean airspeed over the whole course. The accuracy of measurement over a quadrilateral measuring course is considerably enhanced by this correction, as the subjoined results show. This method of correcting the measured results over a quadrilateral course is quite permissible if used only to produce comparative values for checking the accuracy of different measuring methods, since errors due to faults in flying have no real relationship to the method of measurement applied, and will distort the value of the results obtained, unless they are eliminated.

AIR LOG MEASUREMENTS.

The air log is towed on a 30 m. cable and its revolutions recorded by a counter on the aeroplane. At the same time, a stop-watch is intermittently operated, allowing the number of revolutions over given intervals of time to be counted. The instrument errors are exceedingly small; the rotor pitch is about 4.4 m., and at 130 m./sec. airspeed the turning speed of the rotor is about 30 rev. per sec. If the stop-watch timing accuracy is within 0.1 sec. the error in determining the distance flown will be $\Delta S = 30/10 \cdot 4.4 \approx 13$ metres, or a negligibly-small variation of 0.00065 of the total measuring length of about 20,000 metres.

A second source of error is the disturbance of the velocity field about the log rotor by the proximity of parts of the aircraft. This can be allowed for by application of the circulation theory (*cf.* G. Kiel: " The Estimation of Errors in Dynamic Pressure Calibrations with Suspended Static Heads," L.F.F., Vol. 14, p. 310). Under the conditions obtaining in the actual tests, the velocity error was only $\Delta v/v = 0.0006$, and is thus negligible, particularly if the air log is calibrated for the particular aircraft by test flights at low altitude over a quadri-

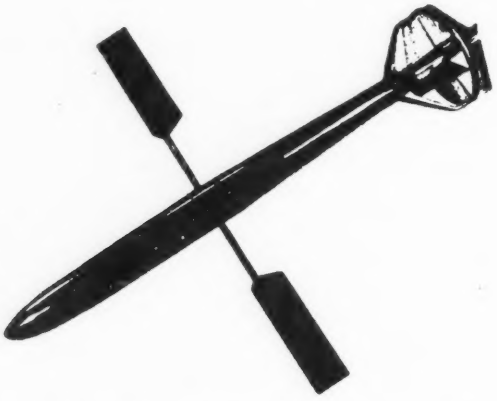


Abb. 1. Ansicht des „Dornier-Schlepplogs" mit neuartigen Belastungsflügeln

Die Feststellung der Logsteigung erfolgte durch häufiges Abfliegen einer Viereckmeßstrecke von etwa 4 × 8 km Länge an verschiedenen Flugzeugen. Aus nachstehender Tabelle kann man ersehen, daß durch Bildung eines statistischen Mittelwertes die Steigung sehr genau ermittelt werden kann.

Eichungen des Schlepplogs Nr. 401

Nr.	Datum	Luftwichte γ [kg/m³]	Fluggeschw. v [m/s]	Logsteigung [m/u]
1	3. 6. 1941	1,150	114,70	4,400
2	3. 6. 1941	1,150	97,65	4,395
3	15. 6. 1941	1,153	87,00	4,407
4	24. 6. 1941	1,130	105,09	4,405
			Mittelwert:	4,402

FIG. 1.

View of " Dornier Air Log " with depressor vanes of new design.

lateral course. The correction obtained by applying the circulation theory does not, however, allow for the influence of downwash and slipstream. It is therefore necessary to prevent the air log from rising under the influence of increasing dynamic pressure in flight. This is most effectively ensured by increasing the weight of the log, but to prevent this exceeding reasonable limits, the " Dornier Air Log " is fitted with " depressor vanes " producing a negative lift on the log, which increases proportionally with the dynamic pressure, balancing the increase in tow-rope lift causing the rotator to rise. By proper adjustment of the depressor vane dimensions and their lift coefficients, the Dornier Air Log can

be made to keep station below the aircraft, equally well at a dynamic pressure of 1,000 kg./m.² with depressor vanes, as at 500 kg./m.² without vanes, and to maintain its position even with further increasing dynamic pressure. The Dornier Air Log is shown in Fig. 1, and weighs about 8.5 kg.

The effective pitch of the log rotor is determined from repeated calibration flights over a quadrilateral measuring course of 4×8 km. with a number of different aircraft. The following table shows that it is possible to determine the pitch very accurately by the formation of a statistical mean value:—

CALIBRATION OF AIR LOG NO. 401.

Run.	Date.	Air Density γ (kg./m³)	Airspeed v (m/sec.)	Log Pitch (m/rev.)
1	3/6/1941	1.150	114.70	4.400
2	3/6/1941	1.150	97.65	4.395
3	15/6/1941	1.153	87.00	4.407
4	24/6/1941	1.130	105.09	4.405
			Mean	4.402

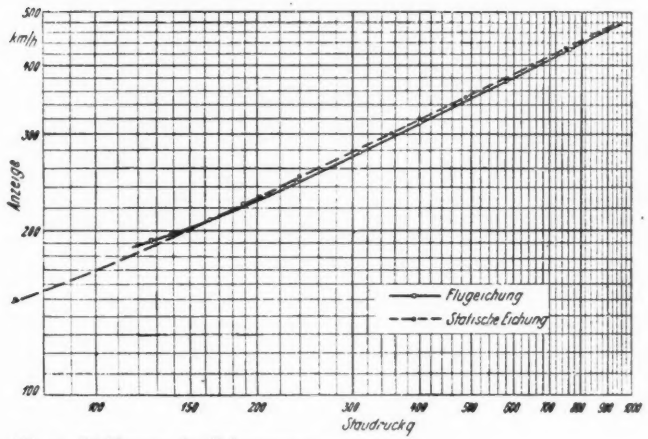


Abb. 2. Eichkurven des Fahrtmessers

FIG. 2.

Calibration curves of the airspeed indicator.

Anzeige	= instrument reading	Flugeichung	= calibration in flight
Staudruck	= dynamic pressure	Statische Eichung	= static calibration

DYNAMIC PRESSURE MEASUREMENTS.

The dynamic pressures were measured by means of an " Askania " pressure head carried on a mast mounted on the fuselage of the test aircraft. This position of the pressure head was selected with a view to least disturbance of the static pressure. The indications of the instrument were recorded in the cockpit by a standard " Askania " airspeed indicator and simultaneously by a D.V.L. duplex self-registering speed recorder. This instrument is equipped with a pressure capsule working up to 1,000 mm. water pressure and since the maximum range of indication could always be used, the accuracy of the readings was the highest possible. The standard airspeed indicator had a measuring range up to 450 km./h.

The instruments were calibrated by repeated flights around a quadrilateral measuring course, the difference between the readings of the calibration flights and the static calibration, representing the correction to be applied to the local

dynamic pressure recorded by the pressure head. The calibration curves are reproduced in Figs. 2 and 3. The curve for the self-registering recorder is plotted to a logarithmic scale, since the theoretical curve then becomes a straight line. The dial of the standard airspeed indicator is calibrated in km./h.

The static pressures were measured by an aneroid box supplied by the firm of R. Fuess, working off the static tube, and the temperatures by an outboard alcohol thermometer. The results of a number of tests showed that these temperature measurements require correction, the registered values being too high on account of the practically adiabatic compression of the airflow past the obstruction represented by the thermometer. The necessary correction was determined experimentally as follows:—

$$\Delta t = -\left(\frac{0.8 \cdot v^2}{2{,}000}\right) (°C.)$$

which has accordingly to be applied to all thermometer readings in flight.

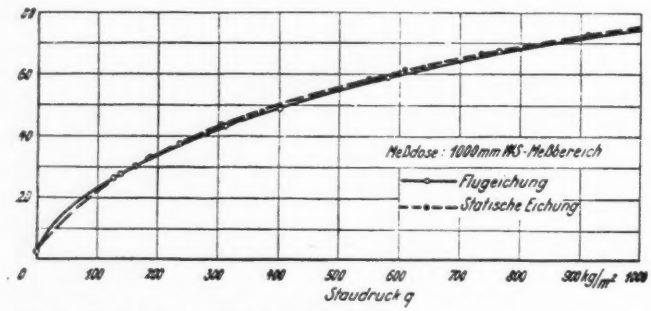


Abb. 3. Eichkurven des DVL-Zweifachschreibers

FIG. 3.

Calibration curves of the D.V.L. duplex recorder.

Messdose	= pressure capsule	Statische Eichung	= static calibration
Messbereich	= measuring range	Staudruck	= dynamic pressure
Flugeichung	= calibration in flight		

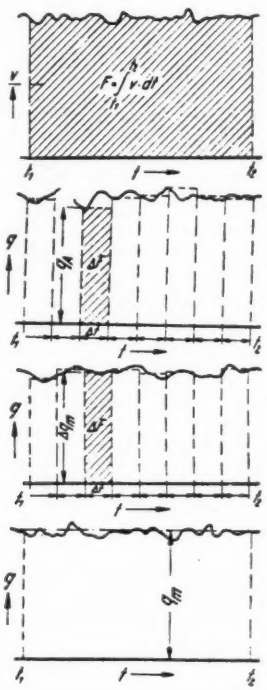
REMARKS ON FORMATION OF THE MEAN VALUES.

In all three methods of airspeed measurement, a mean value over a certain period of time is taken, in the same manner as practised in flight performance tests, in order to smooth out the small variations due to errors of flying. In practice, however, the manner in which the mean value is obtained is different in each of the three methods. A survey of these differences would be exceedingly valuable, as furnishing indications in regard to the relative accuracy, advantages and drawbacks of the different measuring methods. For this purpose, assume the velocity or dynamic pressure values for any given aircraft to be plotted over a certain time interval. For flight around a quadrilateral course, the time mean of the airspeed can be formed directly from the four measured values for the four legs of the course, *i.e.*, by directly measuring the area under the curve of "v" in Fig. 4a, which will represent the distance flown in the air, since

$$S = \int_0^t v \cdot dt.$$

In measurements by the air log, the time mean is formed in the same manner; the revolution counter records the number of revolutions in the time interval determined by the stop-watch, which, multiplied by the pitch of the rotor, gives the actual distance flown through the air.

In the dynamic pressure method, the mean value is established in an entirely different manner: The readings of a pressure-head, or airspeed indicator, are plotted over specific time intervals, by which the dynamic pressure curve becomes broken into a number of sections, the rectangles based on each representing the value of the reading for each interval of time, and the equivalent total area of the airspeed curve being formed by the sum of the partial areas of these rectangles—see Fig. 4b. The accuracy of the resultant mean value will consequently increase with the frequency with which the readings have been taken. Values for specific time intervals can also be obtained from a continuous dynamic-pressure record, and their arithmetic mean formed.



a) Viereckflug und Schlepp ogmessung:

Bildung des wahren zeitlichen Mittelwertes durch direkte Messung der schraffierten Fläche $F = \int v \cdot dt$.

Es ist $v_m = \frac{F}{t_2 - t_1}$

b) Staudruckmessung mit Anzeigegerät:

Bildung des Mittelwertes durch arithmetisches Mitteln aus den Teilflächen ΔF.

Es ist $\Delta F = q_A \cdot \Delta t$

$$q_m = \frac{\Sigma \Delta F}{\Sigma \Delta t}$$

c) Staudruckmessung mit Registriergerät:

Bildung des Mittelwertes durch graphisches Mitteln der Teilmittelwerte und arithmetrisches Mitteln derselben.

Es ist $\Delta q_m = \frac{\Delta F}{\Delta t}$ *und*

$$q_m = \frac{\Sigma \Delta q_m}{\Sigma \Delta t}$$

d) Staudruckmessung mit Registriergerät:

Bildung des Mittelwertes durch graphisches Mitteln des Gesamtverlaufes

Abb. 4 (a bis d). Die vier Möglichkeiten der Mittelwertbildung

FIG. 4*a-d*.

The four methods of finding the mean speed.

a. Quadrilateral flight and air log readings. The true time mean is obtained by direct measurement of the shaded area.

b. Dynamic pressure measurement by airspeed indicator. The mean value is determined arithmetically from the partial areas.

c. Dynamic pressure measurement by airspeed recorder. The mean is found by averaging the partial means graphically and determining the mean of means arithmetically.

d. Dynamic pressure measurement by airspeed recorder. The mean is found by graphically averaging the entire curve.

A still more accurate mean value can be obtained from a continuous dynamic-pressure record, however, by taking the graphical mean of the pressure curve for the requisite number of time intervals and arithmetically averaging the mean of these means—see Fig. 4c. This method is only practicable, however, if the recording strip is run at a sufficiently high speed; otherwise, as in the usual type of roof recorder, it is only possible to obtain the mean over the whole

period of the measurement by graphical averaging—see Fig. 4d. This would appear to be the least accurate method of determining the mean airspeed value.

In flight performance tests, the time mean over a sufficiently long period (not less than 3 mins.) is required, and not the instantaneous value. For this purpose the air log would appear particularly suitable, since the correct mean value is obtained automatically.

RESULTS OF COMPARATIVE AIRSPEED MEASUREMENTS.

The measured distances of the quadrilateral calibration courses were as follows: A-B = 20,309 m.; C-D = 18,248 m. These distances were determined by the Land Survey with ±5 m. accuracy. The course A-B was laid out on a bearing of 305·5°, *i.e.*, 54·5° with N.S.; the course C-D on a bearing of 16.7°, *i.e.*, 16.7 with N.S., Table I, gives the measured values as well as the ground speeds reduced to a mean rotor speed of the log (v_g).

The limits of error of the airspeed measurements in the quadrilateral flights, as given in this table, are exceptionally close. They are stated in the table as the half of one side of the quadrangle of error, to the scale of the velocity. In the least favourable case, the error is ±0.40 m./sec. or 0.31 per cent. of the measured value, while the mean error is only ±0.19 m./sec., or 0.15 per cent. of the measured value. The method of measurement in quadrilateral flight may therefore be considered sufficiently accurate to serve as a basis of comparison.

The effective pitch of the log rotor tends to increase with altitude, owing to the friction in the rotor bearings. The relative importance of the frictional effect will obviously vary inversely as the turning moment exerted by the airflow; which, however, is proportional to the air density γ—*i.e.*, at $\gamma = 0$ the rotator ceases to function, and the apparent pitch becomes infinitely great. If the ratios of log pitch at varying altitudes to log pitch at the ground (4.405) are plotted against the air density γ (Fig. 5), the log altitude correction factors are obtained; it must be remembered, however, that the log pitch is affected by the same errors as the airspeed. Plotting the ratio of altitude pitch/ground pitch against air density produces the curve shown in Fig. 5. The zone of scattering is composed of two sets of values—scattering of the individual values at altitude, and scattering of the reference ground value; obviously, therefore, there is no relationship between altitude and range of scattering—the errors of airspeed measurement are therefore accidental and not related to the altitude. On the other hand, the dependence of effective log pitch on altitude is unquestionable, and there is no reason to assume that the relationship between effective log pitch and air density is other than steady. Consequently, the fair curve for the log pitch must be drawn steadily and always within the range of scattering of the measured values; which leads to the conclusion that the scattering of these values is almost exclusively due to errors inherent in the method of quadrilateral test flights, and not to any unsteadiness in the running of the log rotor, *i.e.*, air log readings are still far more accurate than the results of measurements by means of quadrilateral calibration flights; unfortunately, no more accurate basis of comparison exists.

The high accuracy of air log readings is assured as soon as the effective log pitch has been determined with sufficient accuracy by a sufficient number of low-level calibration flights and the altitude correction calculated from the corresponding curve.

Air log measurements of such high accuracy can consequently be applied to the comparison with dynamic pressure measurements by the standard method. The mean measured dynamic pressure for each leg of the quadilateral course can be converted into the corresponding airspeed and compared with the mean airspeed by log reading; the means of the dynamic pressures being found by one of the methods already indicated, *i.e.*:—

(*a*) Expertly fairing the curve of a continuous dynamic pressure record.

(*b*) Finding the arithmetic mean of separate dynamic pressure readings, taken, *e.g.*, at 10-second intervals, on the continuous record.

(*c*) Finding the arithmetic mean of separate dynamic pressure readings taken by a skilled observer at 10-second intervals.

The resulting values are given in Table II, and the corresponding maximum and mean errors of the dynamic pressure measurement are as follows:—

Method.	a	b	c
Maximum error ...	2.2%	2.04%	2.04%
Mean error	0.92%	0.90%	0.76%

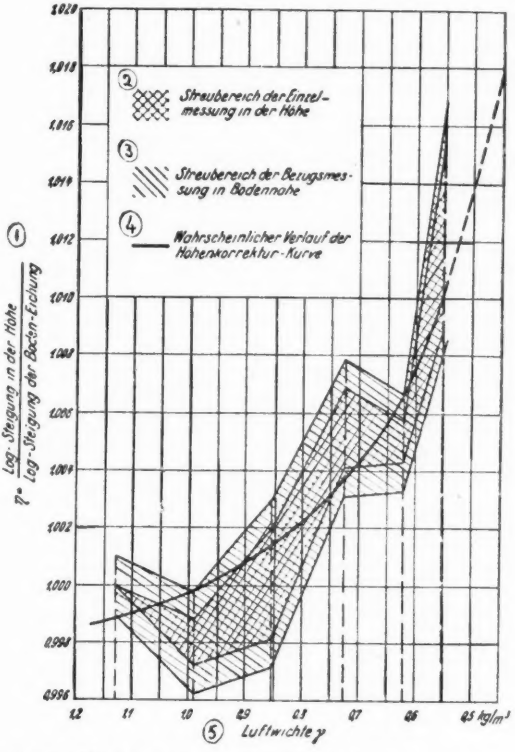


Abb. 5. Höhenkorrektur der Schlepplog-Steigung

FIG. 5.

Altitude correction for log pitch.

1. Log pitch at altitude. Log pitch calibrated at ground level.
2. Scattering range of the individual measurements at altitude.
3. Scattering range of the reference measurement at the ground.
4. Probable altitude correction curve.
5. Air density.

These results lead to the following conclusions:—

1. The most accurate method of dynamic pressure measurement is "*c*," probably because of the high accuracy attainable in reading circular scales, and the absence of deformation of a paper recording strip under the influence of atmospheric humidity. However, the three methods of finding the mean are almost identical, since a skilled operator can obtain a sufficiently accurate mean value by fairing the curve of recorded values.

2. The absolute degree of accuracy of airspeed determination by dynamic pressure measurements is about ± 2 per cent.; of course, only if the measuring range of the instrument is fully utilised. If not, the error must be greater, since reading accuracy is a constant factor. The limits of error of ± 2 per cent. therefore apply to readings within about 80 per cent. of the scale maximum, such as would be the case in actual practice, and indicate the limits of scattering of individual errors. The mean error over a series of measurements along a fair curve may rise to ± 0.9 per cent.

Application of the Different Measuring Methods.

Quadrilateral Calibration Flights.

If the same high accuracy is required as in the present series of experiments, such flights will take up a great deal of time, require particularly good visibility, and be confined to horizontal flying. The method is consequently only applicable to special cases and requirements, apart from low-level calibration flights.

Dynamic Pressure Measurements.

These enable instantaneous dynamic pressures to be determined. Such values are needed in tests involving the determination of aerodynamical constants, *e.g.*, aircraft polars, lift coefficients, airframe forces, etc. Steady airspeed values such as required in performance tests, however, can be determined by this method only to a limited extent, and require laborious methods of evaluation. Dynamic pressure measurements are furthermore unsuitable for determining the influence of small variations in aircraft drag or airscrew efficiency, since the effect of these will usually be less than the errors of measurement.

Air Log Measurements.

These measurements combine highest accuracy with simplicity of evaluation. Since the mean value is produced automatically, the method is particularly suitable for flight performance tests; furthermore, calibration of the measurements by flights over a quadrilateral course can be dispensed with, since calibration of the dynamic pressure measuring instruments can be effected by means of the air log at any altitude and in any flying conditions. Finally, the air log method affords the only possibility of measuring small variations of aircraft drag or airscrew efficiency; such measurements are, however, of greatest practical importance, and an example will now be given of measurements carried out to determine the influence of blade surface condition on airscrew efficiency.

An Example of an Air Log Measurement.

The experiment was directed to determining the influence of surface roughness on the suction side of the blade, on the efficiency of an airscrew at high speeds, and was carried out with a twin-engined aircraft fitted with duralumin airscrews. The measurements were arranged as follows.

The airscrews were tested in three consecutive flights under the following conditions:—

(*a*) With polished blades.
(*b*) Coated with anti-glare varnish.
(*c*) Varnished and sanded.

The distance flown was measured in each run at four different altitudes of 900, 1,400, 1,900, 2,400 m. To eliminate the effects of atmospheric disturbance as far as possible, each flight extended over ten minutes. The pilot was instructed to fly steadily at the same height; flying weight, charging pressure, engine r.p.m., radiator flap setting, etc., were, of course, maintained constant throughout the tests.

The results are reproduced in Fig. 6. The straight lines through the four measuring points show that the loss of speed with reference to a brightly polished blade surface, was $\Delta v/v = 0.7$ per cent. for the surface covered with anti-glare

Nr.	Strecke	Flughöhe über Grund H [m]	Stoppzeit T s	Geschwindigkeit über Grund v_g' [m/s]	Angezeigte Logdrehzahl	Mittlere Logdrehzahl n_{mittl}	Auf mittlere Geschwindigkeit reduz. Geschw. über Grund	Mittlere Geschw. aus Viereck	Max. Fehler aus Fehlerviereck	Logsteigung $\frac{v}{n}$ [m/u]

Nr.	Strecke	Flughöhe über Grund H [m]	Stoppzeit T s	Geschwindigkeit über Grund v_g' [m/s]	Angezeigte Logdrehzahl n_{Log}	Mittlere Logdrehzahl n_{mitt}	Auf mittlere Geschwindigkeit reduz. Geschw. über Grund v_g [m/s]	Mittlere Geschw. aus Viereck v [m/s]	Max. Fehler aus Fehlerviereck Δv [m/s]	Logsteigung $\frac{v}{n}$ [m/u]
1	B—A	200	193,8	104,75	23,86	23,87	104,75	105,09	± 0,10	4,405
2	A—B		193,1	105,15	23,86		105,15		± 0,10 %	±0,10 %
3	C—D		175,1	105,00	23,84		105,10			
4	D—C		174,7	105,45	23,92		105,15			
5	A—B	1500	151,1	134,30	29,56	29,60	134,50	130,00	± 0,10	4,395
6	B—A		162,4	125,00	29,48		125,50		± 0,08 %	± 0,08 %
7	C—D		139,3	132,20	29,50		132,70			
8	D—C		144,2	127,80	29,68		127,50			
9	A—B	3000	150,2	135,10	29,56	29,80	136,20	131,15	± 0,25	4,405
10	B—A		161,2	125,80	29,82		125,70		± 0,19 %	± 0,19 %
11	C—D		133,7	137,80	30,00		136,90			
12	D—C		145,6	126,60	30,00		125,70			
13	A—B	4500	151,4	133,95	31,32	31,40	134,25	139,00	± 0,20	4,428
14	B—A		140,2	144,70	31,58		143,80		± 0,14 %	± 0,14 %
15	C—D		129,3	142,55	31,40		142,55			
16	D—C		137,7	133,80	31,16		134,80			
17	A—B	6000	143,8	141,00	30,86	30,78	140,60	136,30	± 0,10	4,425
18	C—D		133,0	138,50	30,60		139,30		± 0,07 %	± 0,07 %
19	D—C		137,4	134,10	30,80		134,10			
20	B—A		152,6	132,80	30,86		132,50			
21	A—B	7000	160,4	126,30	27,06	28,80	134,40	128,20	± 0,40	4,455
22	C—D		137,8	133,70	28,46		135,30		± 0,31 %	± 0,31 %
23	D—C		148,3	124,20	29,40		121,70			
24	B—A		167,8	120,70	28,60		121,50			

No.
Course.
Flying height above ground, H[m].
Time by stop-watch Ts.
Speed over ground " v_g " (m./sec.).
Indicated log speed, r.p.s., " n_{log}."
Mean log speed, r.p.s., " n_{mitt}."
Speed over ground reduced to mean speed " v_g " (m./sec.).
Mean speed over quadrilateral " v " (m./sec.).
Max. deviation by quadrangle of error " $\triangle v$ " (m./sec.).
Log pitch " v " (metres/revolution).

Zahlentafel 2

Messung Nr.	H über Grund	n_{Log}	Logsteigung	v Log	γ kg/m³	Methode a) q_{m_1}	Methode a) v_{m_1}	Methode b) q_{m_2}	Methode b) v_{m_2}	Methode c) q_{m_3}	Methode c) v_{m_3}	Δv_{m_1} %	Δv_{m_2} %	Δv_{m_3} %
1	7000	27,06	4,455	120,50	0,552	407	120,25	408,7	120,55	403	119,70	— 0,21	+ 0,04	— 0,66
2		28,46		126,75		458	127,55	458,4	127,60	450	126,45	+ 0,63	+ 0,67	— 0,24
3		29,40		130,95		492	132,25	491,4	132,20	497	132,90	+ 0,99	+ 0,96	+ 1,49
4		28,60		127,35		465	128,55	466,5	128,80	475	129,95	+ 0,94	+ 1,14	+ 2,04
5	6000	30,86	4,430	136,65	0,619	603	138,30	603,1	138,30	605	138,50	+ 1,21	+ 1,21	+ 1,35
6		30,60		135,50		590	136,75	589,2	136,65	594	137,25	+ 0,92	+ 0,84	+ 1,29
7		30,80		136,40		596	137,50	597,2	137,60	602	138,15	+ 0,81	+ 0,88	+ 1,28
8		30,86		136,65		599	137,80	599,0	137,80	607	138,75	+ 0,84	+ 0,84	+ 1,54
9	4500	31,32	4,428	138,60	0,724	712	138,90	710,3	138,80	706	138,40	+ 0,22	+ 0,14	— 0,14
10		31,58		139,75		725	140,20	725,5	140,25	713	139,05	+ 0,32	+ 0,36	— 0,50
11		31,40		138,95		718	139,50	717,8	139,50	710	138,70	+ 0,40	+ 0,40	— 0,35
12		31,16		137,90		707	138,45	707,7	138,50	691	136,80	+ 0,40	+ 0,44	— 0,80
13	3000	29,56	4,402	130,05	0,853	743	130,80	741,7	130,70	730	129,65	+ 0,58	+ 0,50	— 0,31
14		29,82		131,25		756	131,95	756,9	132,00	742	130,70	+ 0,53	+ 0,57	— 0,42
15		30,00		132,00		765	132,70	763,8	132,55	751	131,50	+ 0,53	+ 0,42	— 0,38
16		30,00		132,00		773	133,45	775,4	133,65	773	133,45	+ 1,10	+ 1,25	+ 1,10
17	1500	29,56	4,394	129,85	0,989	885	132,55	884,1	132,50	840	129,20	+ 2,08	+ 2,04	— 0,50
18		29,48		129,50		876	131,90	872,5	131,60	837	128,95	+ 1,85	+ 1,62	— 0,42
19		29,50		129,55		883	132,40	880,4	132,20	848	129,75	+ 2,20	+ 2,04	+ 0,15
20		29,68		130,40		885	132,50	885,6	132,60	854	130,20	+ 1,61	+ 1,69	— 0,15
											Mittelwerte	± 0,919	± 0,902	± 0,755
											Maxima	+ 2,20	+ 2,04	+ 2,04

Test No. — Method a)
H over ground — Method b)
n Log — Method c)
Log pitch — $\triangle v_{m_1}$
v log — $\triangle v_{m_2}$
$\triangle$ kg./m.³ — $\triangle v_{m_3}$
Mittelwerte = mean values.

In Zahlentafel 2 sind die Werte zusammengestellt. Daraus ergeben sich folgende maximale und mittlere Fehler bei der Staudruckmessung:

Methode	a)	b)	c)
[illegible]-Fehler	2,2 %	2,04 %	2,04 %

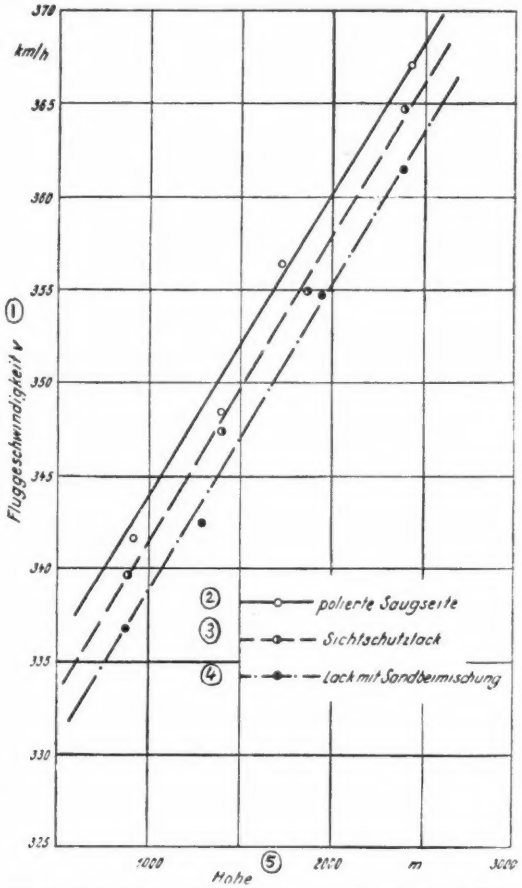


Abb. 6. Beispiel einer Schlepplogmessung über den Einfluß der Rauhigkeit der Luftschrauben-Saugseite auf den Wirkungsgrad

FIG. 6.

Specimen air log measurements in the influence of roughness on the suction side of the blade, on airscrew efficiency.

1. Airspeed.
2. Polished suction side.
3. Anti-glare varnish.
4. Varnished and sanded.
5. Flying height.

and $\Delta v/v = 1.4$ per cent. for the varnished and sanded surface; the corresponding efficiency losses being 2.1 and 4.2 per cent.

SUMMARY.

The relative accuracy and suitability of three available methods of measuring airspeeds in flight have been investigated by carefully-planned and executed flying tests. These showed that the form of air log developed by the Dornier-Werke is the most suitable in regard to simplicity of operation and accuracy. Depressor vanes of a new type allow the log to be used at the highest speeds of flight occurring in practice. Many practical problems are in fact only capable of solution by this method.

REVIEWS.

THE OBSERVER'S BOOK OF AIRPLANES.

Joseph Lawrence. Frederick Warne and Co. 1943. 4/-.

Here is a pocket manual that will really slip into the average pocket, and that, by reason of its well-spaced type and clear photographs and diagrams, can be easily read in a bad light. It should therefore be welcomed by active members of the Observer Corps. From a library point of view, however, the method of classification is somewhat confusing; of the 113 aeroplanes shown, the majority are grouped under type (low-wing monoplanes, etc.), with a three-quarter front flying view and a series of three-view outline drawings. Russian and Japanese machines form two separate sections at the end, and are, in the main, illustrated only by drawings.

AIRCREW EXERCISES FOR THE AIR TRAINING CORPS.

Air League of the British Empire. 1943. 1/-.

This small pamphlet will be a boon to harassed parents and schoolmasters who have a house full of boys to amuse during week-ends or holidays. The games described have been submitted by instructors in the A.T.C., and some of them—such as Formation Cycling and the Morse exercises—have real instructional value. In any case a good time is had by all, as the following "Problem" will show:—

"Problem 10.—Squadron is marching from a bus stop to headquarters a mile away for parade. The following incidents occur: (1) Enemy aircraft overhead; (2) runaway pony and cart comes round a corner; (3) a mad dog comes down the road; (4) screams and smoke come from a house."

THE AIR MARINER—A FLYING-BOAT GUIDE. (2nd Ed.)

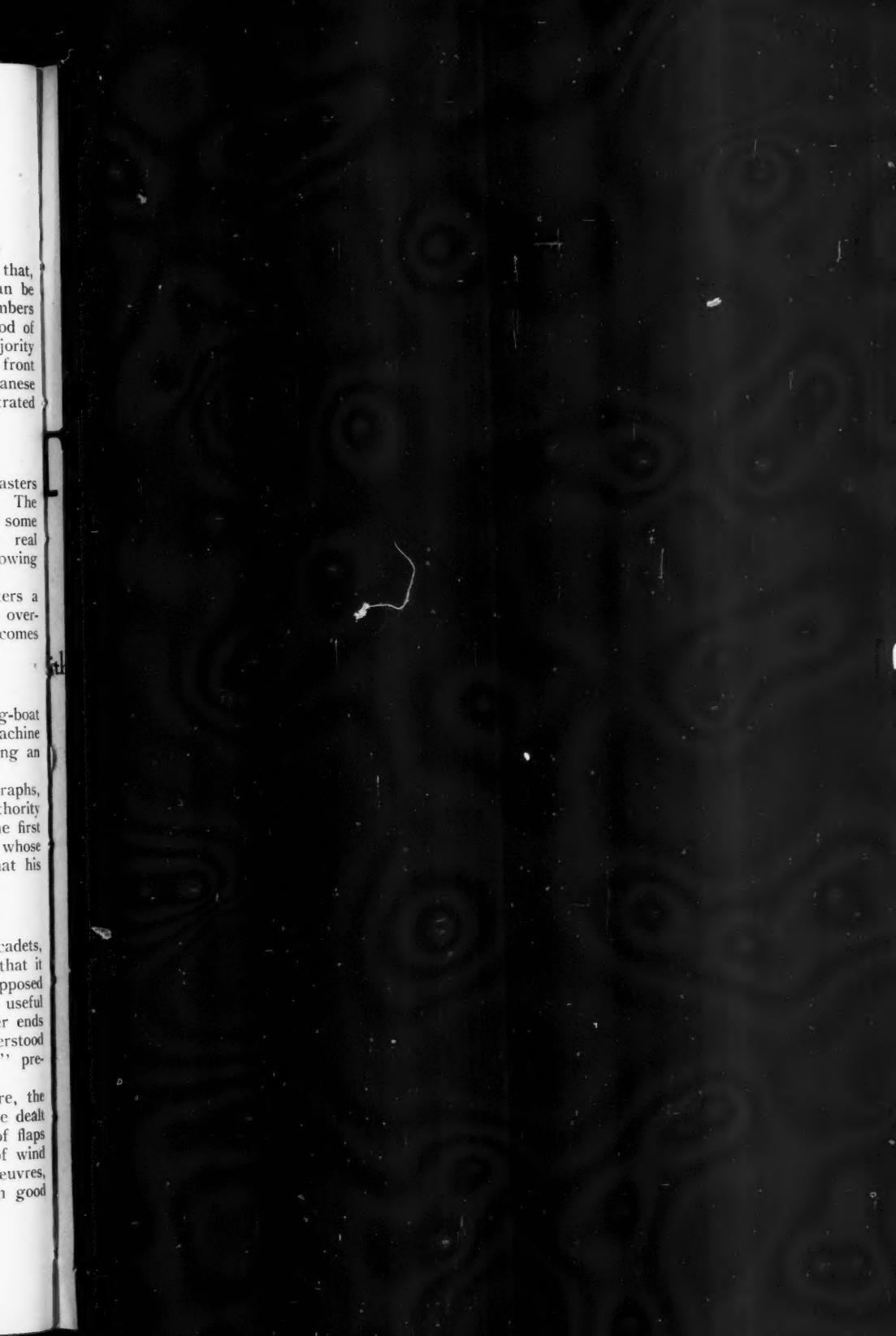
D. C. T. Bennett. Sir Isaac Pitman and Sons. 1943. 7/6.

"The Air Mariner," as its title implies, is a manual of hints to the flying-boat pilot on seamanship—marine equipment and tackle; the handling of his machine at its moorings and during take-off and alighting; suggestions on choosing an anchorage; notes on marine lights, signals and definitions.

With the exception of one or two added diagrams and inserted paragraphs, this edition is identical with the first. It has, however, the added authority conferred by the author's name. The modest "Flying-Boat Pilot" of the first edition now reveals himself as Air Commodore D. C. T. Bennett—a flyer whose achievements in peace and war are in themselves sufficient guarantee that his advice is sound.

AN INTRODUCTION TO THE PRINCIPLES OF FLIGHT.

W. F. Ware. Macmillan and Co., Ltd. 1943. 3/-.

In his preface the author implies that this book is for schoolboys and cadets, but, unless used in class (for which it is eminently suitable), we think that it would prove hard reading for the majority of them. The standard presupposed is at least that of matriculation. Instructors, however, would find it most useful when preparing lessons and lectures, or setting homework. Each chapter ends with questions aimed at finding out whether the student has really understood the principles involved. The words "discuss," "explain," "criticise" predominate, and set sums are in the minority.

After an introduction giving general information about the atmosphere, the subject of streamlining is discussed; the forces acting on an aeroplane are dealt with at some length; excellent diagrams and tables illustrate the effect of flaps and slots; subsequent chapters refer to stability and control, the effect of wind on an aeroplane in flight, forces and accelerations during aerobatic manœuvres, airscrew theory, and altitude effects. The book is fully illustrated with good photographs and diagrams.